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(54) **METHOD AND DEVICE FOR COATING.**

(57) The invention relates to metallurgy. The proposed method for coating of articles provides for introducing into a gas flow the powder of a material chosen from a group consisting of metals, alloys and their mechanical mixtures, or dielectrics, and having a particle size of 1 to about 50 µm, in a quantity sufficient to ensure a mass flux density of the particles of 0.05 to 17 g/sec.cm^2, so as to form a gas-powder mixture which is directed on the surface of the article, the gas flow being given a supersonic speed and being formed into a supersonic jet of a desired profile providing for a speed of the powder particles in the gas-powder mixture of 300-1,200 m/sec. A device for implementation of the method comprises a doser-feeder (1) and, interconnected to each other, a bunker (2) for the powder, a means for dosing it consisting of a horizontally mounted drum (9) with recesses provided along a spiral line on its cylindrical surface (9'), a mixing chamber (3), a nozzle (4) intended for acceleration of the powder particles and connected to the mixing chamber (3), a compressed air source (5) connected to a means for feeding the compressed air to the mixing chamber (3), a flow regulator (11) for the powder articles mounted in relation to the cylindrical surface (9') of the drum (9) with a gap (12) ensuring the required mass flow of the powder, and intermediate nozzle (13) coupled with the mixing chamber (3) and

EP 0 484 533 A1

Technical Field

The invention relates to the metallurgy, and more specifically, it deals with method and apparatus for applying a coating.

Background Art

Protection of structures, equipment, machines, and mechanisms made of ferrous metals against corrosion and action by aggressive media, enhancement of technical characteristics of materials, including the preparation of materials with expected properties, and development of resource-saving manufacturing processes is an important scientific, technological and practical problems.

These problems can be solved by using various methods, including deposition of powder coatings and, among others, with the use of most popular gas flame-spray, electric arc, explosive, and plasma methods.

The gas flame-spray method is based on the use of gas combustion products at 1000 to 3000° C, and creation of a flow of such gases in which particles of the powder being applied are fused. A velocity of 50 to 100 m/s is imparted to particles of the powder, and the surface is treated with the gas and powder flow containing the fused particles. This treatment results in a costing being formed. Low values of velocity and temperature of the applied particles substantially limit application of this method.

The explosive method is partly free of these disadvantages. With this method, energy of detonating gases at 2000 to 3500° C is used so as to substantially increase the velocity of the particles up to 400 to 700 m/s and their temperature, up to 2000 to 3500° C to ensure application of coatings with powders of metals, alloys, and insulating materials. This method is very disadvantageous in a low productivity because of the pulsed character of deposition: the resulting shock wave and a gas flow accompanying it cause a high level of a thermal and dynamic action upon the product and high level of acoustic noise which restricts application of this method.

The most promising is a method of plasma deposition wherein a powder coating is applied to a product surface with a high-temperature gas jet (5000 to 30000° C).

Known in the art is a method for applying coatings to the surface of a product made of a material selected from the group consisting of metals, alloys, and insulating materials, comprising introducing into a gas flow a powder of a material selected from the group consisting of metals, alloys, their mechanical mixtures or insulating materials for forming a gas and powder mixture which is directed towards the surface of a product (in the book by V.V. Kudinov, V.M. Ivanov. Nanesenie Plazmoi Tugoplavkikh Pokryty /Application of Refractory Coatings with Plasma/. Mashinostroenie Publishing House, Moscow. 1981, pp. 9 to 14).

The prior art method is characterized in that powder particles of a size from 40 to 100 μm are introduced into a high-temperature gas flow (5000 to 30000° C) in the form of a plasma jet. Powder particles are heated to the melting point or above that point, accelerated with the gas flow of the plasma jet and directed at the surface being coated. Upon impingement, particles of the powder interact with the surface of the product so as to form a coating. In the prior art method, powder particles are accelerated by the high-temperature plasma jet and are transferred, in the molten state, to the product being coated; as a result, the high-temperature jet runs into the product to exert a thermal and dynamic action upon its surface, i.e., to cause local heating, oxidation and thermal deformations. Thus, thin-walled products are heated up to 550° C, they are oxidized and warped, and the coating peels off.

The high-temperature jet running into the product surface intensifies chemical and thermal processes, causes phase transformations and appearance of over-saturated and non-stoichiometric structures, hence, results in the material structure being changed. In addition, a high level of thermal exposure of the coating results in hardening of heated melts and gas release during solidification which causes formation of a large porosity and appearance of mickrocracks, i.e., impairs technical characteristics of the coating.

It is known that, with an increase in temperature of plasma jet, plasma density in comparison with gas density under normal conditions linearly decreases, i.e., at 10000° C, density of the jet becomes scores of times lower which results in a respective decrease in the coefficient of drag. As a result, with an escape velocity of the plasma jet of 1000 to 2000 m/s (which is about equal to, or slightly below then, the sonic velocity), the particles are accelerated up to 50 to 200 m/s (even up to 350 m/s at best), i.e., the process of acceleration is not efficient enough.

size from 1 to 10 µm to be eliminated, lower level of thermal and erosion exposure of components of the apparatus to be ensured, with a service life of the apparatus being prolonged up to 1000 hours without the use of expensive, refractory, and erosion-resistant materials, with an improvement of operation of the duct in which powder particles are accelerated and with enhanced reliability of the metering feeder in operation even in metering fine powder fractions.

The problem set forth is accomplished by providing a method for applying a coating to the surface of a product made of a material selected from the group consisting of metals, alloys, and insulating materials, comprising introducing into a gas flow a powder of a material selected from the group consisting of metals, alloys, their mechanical mixtures or insulating materials for forming a gas and powder mixture which is directed towards the surface of a product, wherein, according to the invention, the powder used has a particle size from 1 to 50 µm in an amount ensuring flow rate density of the particles between about 0.05 and about 17 g/s cm^2, a supersonic velocity being imparted to the gas flow, and a supersonic jet of a predetermined profile being formed which ensures a velocity of powder in the gas and powder mixture from 300 to 1200 m/s.

Owing to the fact that the powder is used with a particle size from 1 to 50 µm, denser coatings can be produced, filling of the coating layer and its continuity are improved, the volume of microvoids decreases, and structure of the coating becomes more uniform, i.e., its corrosion resistance, hardness, and strength are enhanced.

A density of flow rate of the particles between about 0.05 and about 17 g/s cm^2 increases the degree of utilization of the particles, hence, productivity of coating application. With a flow rate of particles below 0.05 g/s cm^2, the degree of utilization is close to zero, and with the degree of utilization above 17 g/s cm^2, the process becomes economically ineffective.

The formation of the supersonic jet ensures acceleration of the powder in the gas stream and lowers temperature of the gas flow owing to gas expansion upon its supersonic escape. The formation of the supersonic jet of a predetermined profile with a high density and at low temperature, owing to an increase in the coefficient of drag of the particles with an increase in gas density and a decrease in temperature, ensures a more efficient acceleration of powder particles and a decrease in thickness of the compressed gas layer in front of the product being coated, hence, a lower decrease in velocity of the particles in the compressed gas layer, a decrease in the level of thermal and dynamic and thermal and chemical exposure of the surface being coated and particles of the powder being applied, elimination of evaporation of particles of a size from 1 to 10 µm, preservation of the initial structure of the powder material and elimination of hardening of the coating and thermal erosion of components of the apparatus.

Imparting an acceleration to the gas and powder mixture to a velocity of from 300 to 1200 m/s ensures high level of kinetic energy of the powder particles which upon impingement of the particles against the surface of a product is transformed into plastic deformation of the particles and results in a bond being formed between them and the product.

Therefore, the invention, which makes use of finely-divided powder particles of a size from 1 to 50 m with a density of flow rate from 0.05 to 17 g/s cm^2 and which contemplates imparting an acceleration to the powder particles by means of a supersonic jet of a predetermined profile and with a low gas temperature to a velocity of from 300 to 1200 m/s substantially lowers the level of thermal and dynamic and thermal and chemical exposure of the surface being coated and enhances efficiency of particles acceleration so as to ensure the production of denser coating microvoids, enhance the filling of the coating layer and its continuity. This results in a uniform structure of the coating with substantially preserved structure of the powder material without phase transformations and hardening, i.e., the coatings do not crack, their corrosion resistance, microhardness, and cohesion and adhesion strength are enhanced.

It is preferred that the supersonic jet of a predetermined profile be formed by carrying out gas expansion in accordance with a linear law. This facility ensures simplicity and low cost of manufacture of an apparatus for carrying out the method.

It is preferred that the gas flow be formed with a gas at a pressure of from about 5 to about 20 atm. and at a temperature below the melting point of the powder particles. As a result, efficient acceleration of powder particles is ensured because of a low density of the gas, thermal and dynamic and thermal and chemical exposure is lowered, and manufacture of an apparatus for carrying out the method is facilitated and its cost is reduced.

Air can be used as the gas for forming the gas flow. This ensures the acceleration of the powder particles to a velocity of up to 300 to 600 m/s and allows savings to be achieved during coating application.

It is preferred that helium be used as the gas for forming the gas flow. This facility allows a velocity of from 1000 to 1200 m/s to be imparted to the powder particles.

It is preferred that the means for gas supply be provided in the casing of the metering feeder in the form of a passage connecting the interior space of the intermediate nozzle to the interior space of the hopper and also comprise a tube connected to the intermediate nozzle and extending through the hopper, the top part of the tube being bent at 180°. This simplifies the design, enhances reliability in operation, and prevents the powder from getting into the passage during loading of the powder into the hopper.

It is preferred that the apparatus comprise a means for heating compressed gas having a gas temperature control system for controlling velocity of gas and powder mixture with the supersonic jet. This facility ensures gas escape velocity control by varying its temperature so that velocity of powder particles is also controlled.

To enhance heat transfer from the gas heater, the inlet of the means for gas heating may be connected, through a pneumatic line to the mixing chamber of the metering feeder and the outlet can be connected to the nozzle for acceleration of powder particles.

For applying coatings of polymeric materials, it is preferred that the apparatus comprise a forechamber for acceleration of powder particles, the inlets of the means for gas heating and of the inlet pipe of the intermediate nozzle of the metering feeder being connected, by means of individual pneumatic lines to a compressed gas supply and their outlets being connected to the forechamber by means of other individual pneumatic lines.

It is preferred that the heating means be provided with a heating element made of a resistor alloy. This allows the size of the heating means and its weight to be reduced.

To lower heat losses and enhance economic effectiveness of the apparatus, it is preferred that the heating element be mounted in a casing having a heat insulator inside thereof.

To make the heating means compact and to ensure heating with low temperature differentials between the gas and the heating element, the heating element may be made in the form of a spiral of a thin-walled tubes, with the gas flowing through the tube.

To ensure a substantial reduction of the effect of the gas supplied to the gas and powder mixture from the metering feeder on operation of the supersonic nozzle, it is preferred that the forechamber have a diaphragm mounted in its casing and having ports for evening out the gas flow over the cross-section and a pipe coaxially mounted in the diaphragm for introducing powder particles, the cross-sectional area of the pipe being substantially 5 to 15 times as small as the cross-sectional area of the pneumatic line connecting the gas heating means to the forechamber.

To lower wear of the drum, alterations of its surface, and reduce jamming, the drum may be mounted for rotation in a sleeve made of a plastic material which engages the cylindrical periphery of the drum.

The plastic material of the sleeve may be in the form of a fluoroplastic (teflon). This allows the shape of the drum to be retained owing to the absorption of the powder by the sleeve material.

Brief Description of the Drawings

The invention will now be described in detail with reference to specific embodiments illustrated in the accompanying drawings, in which:

Fig. 1 is a general view of an apparatus for applying a coating to the surface of a product according to the invention, a longitudinal section;

Fig. 2 is a detail in a view taken along arrow A in Fig. 1 showing location of depressions on the surface of a metering drum;

Fig. 3 is a cross-sectional view taken along line III-III in Fig. 1 showing a cross-section of the supersonic part of a nozzle;

Fig. 4 schematically shows an embodiment of an apparatus for applying a coating to the surface of a product having a gas heating means which is connected in series with the metering feeder according to the invention;

Fig. 5 is another embodiment of an apparatus according to the invention having a gas heating means connected in parallel with the metering feeder;

Fig. 6 is an enlarged view partially in section in Fig. 1.

Best Mode to Carry out the Invention

The invention contemplates a method for applying a coating to the surface of a product. The material of the product is selected from the group consisting of metals, alloys and insulating materials. In this case the materials may be in the form of a metal, ceramic or glass. The method consists in that a powder of a material selected from the group consisting of metals, alloys or their mechanical mixtures, and insulating

To ensure uniform filling of depressions 10 with powder and enhance its reliable admission to mixing chamber 3, drum 9 is mounted to extend horizontally in such a manner that one portion of its cylindrical periphery 9' is used as a bottom 16 of hopper 2 and the other portion forms a wall 17 of mixing chamber 3. Depressions 10 in cylindrical periphery 9' of drum 9 extend along a helical line (Fig. 2) so as to lower fluctuations of the flow rate of powder particles during metering. To impart to the gas flow a supersonic velocity with a predetermined profile, with high density and at low temperature, and also to ensure acceleration of powder particles to a velocity ranging from 300 to 1200 m/s, nozzle 4 for acceleration of particles is in the form of a supersonic nozzle and has a passage 18 of a profiled cross-section (Fig. 3). Passage 18of nozzle 4 has one dimension "a" of its cross-sect on which is larger than the other dimension "b", and the ratio of the smaller dimension "b" of the cross-section at an edge 19 of nozzle 4 (Fig. 1) to length "1" of a supersonic portion 20 of passage 18 ranges from about 0.04 to about 0.01.

This construction of passage 20 allows a gas and powder jet of a predetermined profile to be formed, ensures efficient acceleration of the powder, and lowers velocity decrease in the compressed gas layer in front of the surface being coated.

A swirl member 21 for swirling the gas flow admitted to nozzle 13 through pipe 8 and leaving the means for compressed gas supply is provided on the inner surface of intermediate nozzle 13, at the outlet thereof in mixing chamber 3. This swirl member 21 ensures an effective removal of powder and formation of a gas and powder mixture. To provide a recoil flow and ensure an effective mixing of powder and gas when the gas flow runs into the portion of cylindrical periphery 9' of drum 9 forming wall 17 of mixing chamber 3, intermediate nozzle 13 is mounted in such a manner that its longitudinal axis O-O extends at an angle from 80 to 85° with respect to a normal "n-n" drawn to cylindrical periphery 9' of drum 9.

The apparatus for applying a coating to the surface of a product also comprises a means for supplying compressed gas to depressions 10 in cylindrical periphery 9' of drum 9 and to a top part 22 of hopper 2 so as to even out pressure in hopper 2 and in mixing chamber 3. This facility allows the effect of pressure on metering of the powder to be eliminated.

The means for gas supply is in the form of a passage 23 in casing 1' of metering feeder 1 which connects an interior space 24 of intermediate nozzle 13 to top part 22 of hopper 2 and has a tube 25 which is connected to intermediate nozzle 13, extends through hopper 2 and is bent, at its top part, at 180°.

The means constructed as described above ensures reliable operation and prevents powder from getting into passage 23 when the powder is loaded into hopper 2.

To facilitate control of gas escape velocity by varying its temperature, hence, velocity of powder particles, another embodiment of the apparatus has a means 27 (Fig. 4) for heating compressed gas and a gas temperature control system which allow gas and powder mixture velocity to be controlled when it moves through nozzle 4 for acceleration of powder particles.

The gas temperature control system has a power supply 28 which is electrically coupled, via terminals 29, by means of cables 30, to a gas heating means, a temperature indicator 31, and a thermocouple 32 engageable with the body of nozzle 4.

Gas heating means 27 is connected in series with metering feeder 1.

To enhance heat transfer from the heater to gas, an inlet 33 of means 27 for heating compressed gas is connected, by means of a pneumatic line 34, to mixing chamber 3 of metering feeder 1, and its outlet 35 is connected, by means of a pneumatic line 36, to nozzle 4 for acceleration of powder particles.

If a coating is applied with polymeric materials, the apparatus is provided with a forechamber 37 (Fig. 5) mounted at the inlet of nozzle 4 for acceleration of powder particles. Inlet 33 of means 27 for heating compressed gas and an inlet 38 of metering feeder 1 are connected by means of individual pneumatic lines 39 to compressed gas supply 5, and their outlets 35 and 40 are connected, by means of other pneumatic lines 41, to forechamber 37. This embodiment of the apparatus has the parallel connection of means 27 for gas heating to metering feeder 1. Means 27 for compressed gas heating has a casing 42 (Fig. 4) which has an inner heat insulator 43. Casing 42 accommodates a heating element 44 made of a resistor alloy in the form of a spiral of a thin-walled tube in which the gas flows.

To reduce the effect of the gas supplied from metering feeder 1 on operation of supersonic nozzle 4, forechamber 37 has a diaphragm 45 (Fig. 5) mounted therein and having ports 46 for evening out gas velocity over the cross-section, and a pipe 47 mounted in forechamber 37 coaxially with diaphragm 45 for introducing powder particles from metering feeder 1. The cross-sectional area of pipe 47 is substantially 5 to 15 times as small as the cross-sectional area of pneumatic line 41 connecting means 27 for gas heating to forechamber 37.

Drum 9 is mounted for rotation in a sleeve 48 (Fig. 6) made of a plastic material which engages cylindrical periphery 9' of drum 9.

Table 1

No.	Flow rate density, g/s cm^2	Treatment time,	Coating thickness, m	Change in temperature of heat-insulated support, °C
1	0.01	1000	-	2
2	0.05	20	8	6
3	0.05	100	40	6
4	0.10	100	90	14
5	0.15	100	150	20
6	0.3	100	390	45

It can be seen from the Table that the coating is formed with a flow rate density of powder from 0.05 g/s cm^2 and up. With an increase in density of powder flow rate up to 0.3 g/s cm^2, temperature of the heat insulated support increases up to 45°C.

It follows from the above that coatings can be applied under the above-mentioned conditions, and products have a minimum exposure to thermal effects.

Examples 2, 3, 4, 5 and 6.

The apparatus shown in Fig. 1 was used for coating application.

The material of deposited powders was copper, aluminium, nickel, vanadium, an alloy of 50% of copper, 40% of aluminium, and 10% of iron.

The support material was steel, duralumin, brass, and bronze, ceramics, glass: the support was used without heat insulation.

Operation conditions of the apparatus:

gas pressure	15 to 20 atm.;
gas deceleration temperature	0 to 10°C;
Mach number at the nozzle edge	2.5 to 3;

working gas- mixture of air and helium with 50% of helium;

gas flow	20 to 30 g/s;
particle flow rate density	0.05 to 17 g/s cm^2.

The velocity of particles was determined by the method of laser Doppler anemometry, and the coefficient of utilization of particles was determined by the weighting method.

The results are given in Table 2

Table 3

Powder material	Air temperature, °C					
	10	30	100	200	350	400
aluminium	0.1-1%	1-1.5	10	30-60	90-95	
zinc	1-2	2-4	10	50-80		
tin	1-30	80-40	40-60			
copper			10-20	50	80-90	90
nickel				20	50-80	80-90
titanium				50-80	-	-
iron				20-40	60-70	80-90
vanadium		-		20	40-50	60-70
cobalt				20	40-50	50-60

It can be seen from Table 3 that when air is used as working gas at room temperature, high-quality coatings can be produced from powders of such plastic metals as aluminium, zinc, and tin. A slight air heating to 100-200°C resulting in an increase in particle velocity allows coatings to be produced from the majority of the above-mentioned metals. The product temperature does not exceed 60 to 100°C.

Example 8

The apparatus shown in Fig. 5 was used for coating aplication.

Mach number at the edge of the nozzle	1.5 to 2.6;
gas pressure	5 to 10 atm;
gas temperature	30 to 180°C;
working gas	air;
gas flow	18 to 20 g/s;
powder flow	0.1 to 1 g/s;
powder particle size	20 to 60 µm.

A polymer powder was applied to products of metal, ceramics, and wood. A coating thickness was from 100 to 200 µm. Further thermal treatment was required for complete polymerization.

It can be seen from the above that the invention makes it possible to;

- apply coatings from several dozens of microns to several millimeters thick of metals, their mechanical mixtures, alloys, and insulating materials to products of metals, alloys, and insulating materials, in particular, to ceramics and glass with a low level of thermal exposure of the products;
- apply coatings with fine powders, with particle size between 1 and 10 µm without phase transformations, appearance of oversaturated structures, and hardening during coating formation;
- enhance efficiency of acceleration of the powder owing to the use of compressed high-density gases;
- substantially lower thermal exposure of components of the apparatus.

The construction of the apparatus ensures its operation during at least 100 hours without the employment of expensive erosion-resistant and refractory materials, high throughput capacity which is substantially unlimited because of the absence of thermally stressed components so that this apparatus can be incocporated in standard flow lines to which it can be readily matched as regards the throughput capacity, e.g., in a flow line for the manufacture of steel pipes having protective zinc coatings.

Industrial Applicability

The invention can be most advantageously used, from manufacturing and economic point of view in restoring geometrical dimensions of worn parts increasing wear-resistance, protecting of ferrous metals against corrosion.

The invention may be advantageously used in metallurgy, mechanical engineering, aviation and agricultural engineering, in the automobile industry, in the instrumentation engineering and electronic technology for the application of corrosion-resistant, electrically conducting, antifriction, surface-hardening,

11. An apparatus according to claim 8, **characterized** in that the intermediate nozzle (13) is mounted in such a manner that its longitudinal axis (0-0) extends at an angle from 80 to 85° with respect to the normal (n-n) to the cylindrical surface (9') of the drum (9).

12. An apparatus according to claim 8, **characterized** in that the apparatus comprises a means for supplying compressed gas to depressions (10) in the cylindrical periphery (9') of thedrum (9) and to the upper part (22) of the hopper (2) so as to even out pressure in the hopper (2) and mixing chamber (3).

13. An apparatus according to claim 12, **characterized** in that the means for gas supply is made in the casing (1') of the metering feeder (1) in the form of a passage (23) connecting the interior space (24) of the intermediate nozzle (13) to the interior space (22) of the hopper (2) and also comprises a tube (25) connected to the intermediate nozzle (13) and extending through the hopper (2), the top part (26) of the tube being bent at 180°.

14. An apparatus according to claim 8, **characterized** in that the apparatus comprises a means (27) for heating compressed gas having a gas temperature control system for controlling velocity of gas and powder mixture in the nozzle (4) for powder particle acceleration.

15. An apparatus according to claim 14, **characterized** in that the inlet (33) of the means (27) for gas heating is connected, through a pneumatic line (34) to the mixing chamber (3) of the metering feeder (1) and the outlet (35) is connected to the nozzle (4) for acceleration of powder particles.

16. An apparatus according to claim 14, **characterized** in that it comprises a forechamber (37) mounted in the inlet of the nozzle (4) for acceleration of powder particles, the inlets (33, 38) of the means (27) for gas heating and of the inlet pipe of the intermediate nozzle (13) of the metering feeder (1) being connected, by means of individual pneumatic lines (39) to a compressed gas supply (5) and their outlets (35, 40) being connected to the forechamber (37) by means of other individual pneumatic lines (41).

17. An apparatus according to claim 14, **characterized** in that the heating means (27) is provided with a heating element (44) made of a resistor alloy.

18. An apparatus according to claim 17, **characterized** in that the heating element (44) is mounted in a casing (42) having a heat insulation (43) inside thereof.

19. An apparatus according to claim 17, **characterized in that the** heating element (44) is made in the form of a spiral of a thin-walled tube, with the gas flowing through the tube.

20. An apparatus according to claim 17, **characterized** in that the forechamber (37) has a diaphragm (45) mounted in its casing and having ports (46) for evening out the gas flow over the cross-section and a pipe (47) coaxially mounted in the diaphragm for introducing powder particles, the cross-sectional area of the pipe being substantially 5 to 15 times as small as the cross-sectional area of the pneumatic line (41) connecting the gas heating means (27) to the forechamber (37).

21. An apparatus according to claim 8, **characterized** in that the drum (9) is mounted for rotation in a sleeve (48) made of a plastic material which engages the cylindrical periphery (9') of the drum (9).

22. An apparatus according to claim 21, **characterized** in that the plastic material of the sleeve (48) is fluoroplastic (teflon).

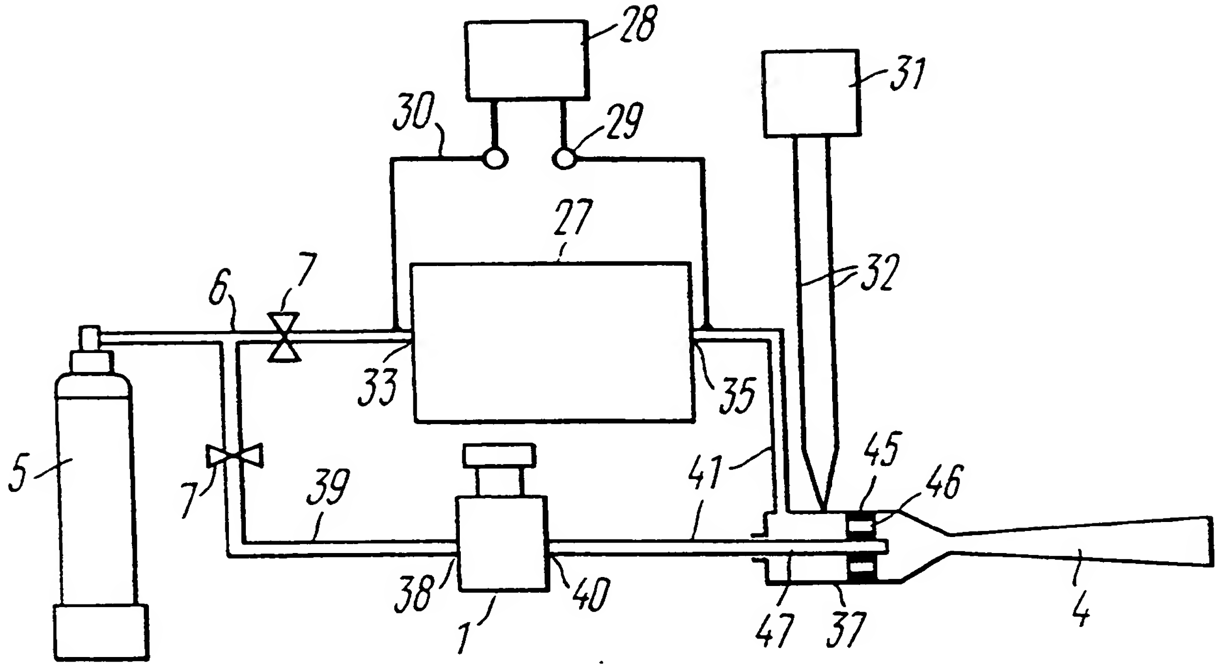

FIG. 5

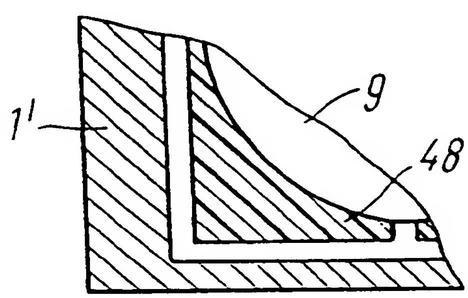

FIG. 6